

# Brain–Behavior Correlation in Children Depends on the Neurocognitive Network

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**Abstract:** We examined brain–behavior correlations in 12 children (age range 9.3 to 11.7 years) during a selective attention task that required the visual search of a conjunction of features and during a response inhibition task that required the inhibition of a pre-potent response during “no-go” blocks. We found that the association between performance in these tasks and brain activation as measured by functional magnetic resonance imaging (fMRI) depended on the neurocognitive network. Specifically, better performance during the no-go task was associated with greater activation in the response inhibition network including the prefrontal cortex and basal ganglia. In contrast, better performance during the visual search task was associated with less activation in the selective attention network including superior parietal lobule and lateral premotor cortex. These results show that the relation of performance to the magnitude of neural activation is complex and may display differential relationships based on the cognitive domain, anatomical region, and perhaps also developmental stage. *Hum Brain Mapp* 23:99–108, 2004.

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**Key words:**

## INTRODUCTION

The neurocognitive networks subserving spatial selective attention and response inhibition are fairly well understood in adults. The network for spatial selective attention includes the posterior parietal cortex and the lateral premotor cortex. It appears that the posterior parietal cortex is associ-

ated with representations of extrapersonal space and the lateral premotor cortex is associated with the organization of orienting and search behaviors [Mesulam, 1990]. In addition to evidence based on focal lesions, numerous functional imaging experiments have confirmed and elucidated the nature of this organization using overt and covert attention paradigms [Corbetta, 1998; Gitelman et al., 1999; Kim et al., 1999; Nobre et al., 2000] as well as paradigms involving the visual search of a conjunction of features [Ashbridge et al., 1997; Corbetta et al., 1995; Donner et al., 2000; Walsh et al., 1999]. A similar set of data has established the existence of a response inhibition network including the prefrontal cortex and basal ganglia (caudate, putamen, and globus pallidus). According to Casey et al. [2001], the prefrontal component of this network prevents the capture of neural processing resources by competing aspects of ambient information,

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whereas the basal ganglia mediate motor inhibition. The involvement of these regions in response inhibition is supported by research in a variety of tasks including go “no-go” paradigms [Kawashima et al., 1996; Konishi, 1998; Liddle et al., 2001; Menon et al., 2001; Rubia et al., 2000; Waldvogel, 2000].

Developmental differences have been identified in the organization of these networks. Using functional magnetic resonance imaging (fMRI), Booth et al. [2003] reported that children showed more activation than adults during a go no-go task in several fronto-striatal regions including medial frontal gyrus, medial aspects of bilateral superior frontal gyrus and the left caudate nucleus [Booth et al., 2003]. However, in a visual search task involving the detection of a conjunction of features (red triangle) in a field of distracters (blue triangles and red trapezoids), there were no significant developmental differences in the superior parietal lobule or the lateral premotor cortex. They attributed the larger differences for response inhibition than for selective attention to delayed maturation of the fronto-striatal network requiring greater mobilization of neural processing resources to achieve similar goals. Indeed, several lines of research have revealed delayed maturation of the prefrontal region as determined by studies of synaptogenesis [Huttenlocher and Dabholkar, 1997], gray matter volume [Sowell et al., 1999], myelination [Giedd et al., 1999], and resting level metabolism [Chugani et al., 1987]. Morphological studies of the striatum also show prolonged changes in volume of the head of the caudate nucleus [Thompson et al., 2000].

Developmental differences in spatial selective attention have not been investigated with fMRI or positron emission tomography (PET). However, a few studies using fMRI have examined visual spatial working memory in developmental populations [Thomas et al., 1999]. These studies are relevant because research with adults has demonstrated that working memory is subserved by a network overlapping the network for spatial attention, including its posterior parietal and lateral premotor components [LaBar et al., 1999]. Nelson et al. [2000] could not find a consistent relationship between accuracy and brain activation in 8- to 11-year-olds. Similarly, Kwon et al. [2002] reported that there was no significant brain-behavior correlation after controlling for age in their study of 7- to 22-year-old subjects. However, Klingberg et al. [2002] reported that higher working memory as measured outside of the scanner in 9- to 18-year-old subjects was associated with more activation in the left superior frontal sulcus and left intraparietal cortex.

Most fMRI studies that have examined brain-behavior correlations in children during go no-go tasks have shown that better performance is associated with greater activation in a fronto-striatal network including the prefrontal cortex and basal ganglia. Although they noted no brain-behavior correlations in the fronto-striatal network for adults, Bunge et al. [2002] reported success in response suppression was associated with greater activation in several regions including the globus pallidus for 8- to 12-year-old children. Durston et al. [2002] reported that higher accuracy was associ-

ated with greater activation in the left caudate nucleus and bilateral inferior frontal gyri for a group of children (6- to 10-year-olds) and adults. Casey et al. [1997] reported that fewer false alarms were associated with a larger volume of activation in the orbital frontal cortex for 7- to 12-year-old children. Non-significant trends for positive and negative correlations of activation with reaction time were reported in a study of 8- to 20-year-old subjects [Tamm et al., 2002].

In general, the existing literature suggests that better performance on response inhibition tasks is associated with greater activation in the fronto-striatal network, whereas there is a weak or nonexistent brain-behavior correlation for working memory tasks that rely on spatial selective attention. However, we are not aware of any studies that have directly compared brain-behavior correlations in response inhibition and spatial selective attention tasks. Because spatial selective attention seems to mature earlier than response inhibition [Booth et al., 2003], we wanted to determine whether brain-behavior correlations for these two neuro-cognitive networks would depend on maturity. Different brain-behavior correlations could provide additional evidence for different developmental trajectories of selective attention and response inhibition. In addition, most of the studies examining brain-behavior correlations in developmental populations have not controlled for age differences. We chose to study children in a limited age range of less than 2.5 years (9.3- to 11.7-year-olds) in order to reduce the potential effects of age on brain-behavior correlations.

## SUBJECTS AND METHODS

### Participants

Twelve healthy children (mean age, 10.9 years; age range, 9.3–11.7 years) participated in the fMRI study, comprising 7 males and 5 females. Children were recruited from the Evanston, Illinois community. Parents of children were given an informal interview to insure that they met the following inclusionary criteria: (1) native English speakers, (2) normal hearing and normal or corrected-to-normal vision, (3) free of neurological diseases or psychiatric disorders, (4) not taking medication affecting the central nervous system, (5) no history of intelligence, reading, or oral-language deficits, and (6) no learning disability or attention deficit hyperactivity disorder (ADHD).

### Functional Activation Tasks

Both the selective attention and response inhibition task involved red triangle targets that were presented on 50% of the trials. The non-target stimuli (distracters) were blue triangles and red trapezoids. Each stimulus was displayed for 1,400 ms followed by an interval (blank screen) that was either 450, 600, or 750 ms. The average inter-stimulus interval was 2,000 ms. Both tasks consisted of 12 blocks and each block consisted of 18 trials plus a one-word instruction screen presented for 3 s at the beginning of each block.

For the selective attention task, blocks with one and nine stimuli were alternated (6 blocks of each). In the blocks with

one stimulus, only one shape was presented at a time and each distracter (a blue triangle or red trapezoid) was presented on 25% of the trials. In the blocks with nine stimuli, nine shapes were presented in a  $3 \times 3$  matrix including 4 of each distracter plus either a target or another distracter. For blocks with one and nine stimuli, the participant pressed his or her index finger if the target was present and the middle finger if the target was absent. For the response inhibition task, go and no-go blocks were alternated (6 blocks of each). In both blocks, trials consisted of nine stimuli. In the go blocks, the participants pressed their index finger as quickly as possible once the shapes appeared on the screen, regardless of whether or not a target was present. In the no-go blocks, the participants pressed their index finger as quickly as possible once stimuli appeared, withholding their finger press only if the target was present.

### Experimental Procedure

After informed consent was obtained, the participant was acclimated to the scanner environment in a simulator [Rosenberg et al., 1997] in which the participant practiced a full-length version of each experimental task. For the MRI session, the head position was secured with a specially designed vacuum pillow (Bionix, Toledo, OH). An optical response box (Lightwave Medical, Burnaby, Canada) was placed in the participant's right hand. The head coil was positioned over the participant's head and a goggle system for the visual presentation of stimuli (Avotec, Jensen Beach, FL) was secured to the head coil. All images were acquired using a 1.5 Tesla General Electric scanner. For the functional imaging studies, a susceptibility weighted single-shot EPI (echo planar imaging) method with BOLD (blood oxygenation level-dependent) was used. The following scan parameters were used: TE = 40 ms, flip angle =  $90^\circ$ , matrix size =  $64 \times 64$ , field of view = 22 cm, slice thickness = 4 mm (no gap), number of slices = 32; TR = 3,000 ms). At the end of the functional imaging session, a high resolution, T1-weighted 3-D image was acquired (SPGR, TR = 21 ms, TE = 8 ms, flip angle =  $20^\circ$ , matrix size =  $256 \times 256$ , field of view = 22 cm, slice thickness = 1 mm).

### Data Analysis

Data analysis was performed using SPM-99 [Friston et al., 1994, 1995a,b]. The functional images were realigned to the last functional volume in the scanning session using affine transformations. No individual runs had more than 2.0 mm movement ( $<1/2$  voxel size) from the beginning to the end of the run in the  $x$ -,  $y$ -, or  $z$ -plane. Co-registered images were normalized to the Montreal Neurological Institute (MNI) stereotaxic template (12 linear affine parameters for brain size and position, 8 nonlinear iterations and  $2 \times 2 \times 2$  nonlinear basis functions). Considering the age of our participants and our voxel size, it was reasonable to normalize all participants into the standard MNI template [Burgund et al., 2002; Kang et al., 2003; Muzik et al., 2000; Wilke et al., 2002]. Statistical analyses were calculated on the smoothed data (7 mm isotropic Gaussian kernel).

The association of accuracy (false alarms or misses) or reaction time with brain activation was determined separately for the visual search blocks with nine stimuli and for the no-go blocks. We did not examine brain-behavior associations during the visual search blocks with one stimulus or the go blocks because these blocks had high accuracy and low reaction times and placed little demand on the selective attention and response inhibition networks, respectively. Furthermore, we could not examine false alarms during the go blocks of the response inhibition task because errors could only involve misses. Consequently, the data for the visual search blocks with one stimulus and the go blocks were not considered further.

We examined the relation between behavioral performance as a continuous measure and the intensity of activation. A design matrix was created to include all fMRI data from each child, and the preliminary threshold for activation was removed in order to estimate each voxel's intensity of activation during each condition relative to the global mean intensity. Raw error or reaction time scores on the tasks were converted into z-scores by subtracting each individual's error rate (false alarms or misses) or reaction time from the mean for that subject group. This z-score resulted in a mean of 0 with individuals with higher errors rates or reaction times having a positive z-score and those with lower error rates or reaction times having a negative z-score. These z-scores were entered as a T-contrast in the statistical analysis for the experimental condition of interest (either the selective attention or response inhibition blocks). This procedure weights the beta estimates of each voxel's signal intensity relative to the global mean by the individual's accuracy or reaction time, thereby testing for a systematic relationship between voxel intensity and performance. A significant effect in this comparison (positive association) would mean that greater intensity activation was associated with poorer performance (higher error rates or reaction time). We then reversed the signs of the z-scores so that those with lower error rates or reaction times had positive z-scores and those with higher error rates or reaction times had negative z-scores. A significant effect in this comparison (negative association) indicated that greater intensity activation was associated with better performance (lower error rates and reaction time). All reported areas of activation are significant using  $P < 0.001$  uncorrected at the voxel level and contain a cluster size greater than or equal to 30 voxels. For each maxima within an activation site, beta estimates of signal magnitude relative to the global mean were also plotted against behavioral performance so that we could confirm that individual subjects were not driving the SPM maps. Although these plots were calculated for all clusters of significant activation, we only present figures for our regions of interest including the superior parietal lobule for the selective attention task and for prefrontal regions and the basal ganglia for the response inhibition task.

**TABLE I. False alarms, misses and reaction times on the selective attention and response inhibition tasks**

Task	False alarms	Misses	Reaction times
Selective attention	3.8 (0.8)	1.4 (0.3)	853 (29)
Response inhibition	5.6 (0.9)	0.6 (0.2)	813 (33)

Values are expressed as mean (SE).

## RESULTS

Table I presents the means and standard errors for accuracy and reaction time on the selective attention and response inhibition tasks. Misses indicate that the participant did not press a button during the response interval. False alarms for the selective attention task indicate that the participant pressed “yes” when the answer was “no” or pressed “no” when the answer was “yes,” whereas false alarms for the response inhibition task indicate that the participant pressed the button when they should have withheld a response. Reaction times for the selective attention task indicate the response time for either a correct “yes” or “no” response, whereas reaction times for the response inhibition task indicate the response time to press the button when the target was present. *T*-tests revealed that there were no significant differences between tasks for misses or reaction times. However, the response inhibition task produced more false alarms than the selective task,  $t(1,11) = 3.43$ ,  $P < 0.01$ . We also calculated intercorrelations between all of the behavioral measures. The only correlations that were significant were between false alarms on the selective attention and response inhibition task,  $r(12) = 0.84$ ,  $P < 0.001$ , between false alarms and misses on the selective attention task,  $r(12) = 0.66$ ,  $P < 0.05$ , and between reaction times on the selective attention and response inhibition task,  $r(12) = 0.83$ ,  $P < 0.01$ .

Table II presents the brain–behavior associations of accuracy or reaction time with intensity activation for the selective attention task. Better performance (higher accuracy) was associated with greater activation in visual processing regions including middle occipital gyrus, cuneus, and precuneus. Poorer performance (lower accuracy) was associated with greater activation in our regions of interest including middle frontal gyrus (lateral premotor cortex) and superior parietal lobule (see Fig. 1). Scatterplots of the correlation between false alarms or misses and activation indicated that the brain–behavior association was not influenced by particular individuals (see Fig. 2). Higher reaction time presumably reflects poorer performance and was also associated with activation in the middle frontal gyrus and the paracentral lobule of the parietal lobe. There were several other clusters of greater activation associated with poorer performance (lower accuracy) including angular gyrus, middle temporal gyrus, middle cingulate, posterior cingulate, posterior central gyrus, and precuneus.

Table III presents the brain–behavior associations of accuracy or reaction time with intensity activation for the

response inhibition task. Better performance (higher accuracy) was associated with greater activation in our fronto-striatal regions of interest including caudate, putamen, inferior frontal gyrus, and medial frontal gyrus (see Fig. 3). Scatterplots of the correlation between false alarms or misses and activation indicated that the brain–behavior association was not influenced by particular individuals (see Figs. 4 and 5). Lower reaction time presumably reflects better performance and was also associated with activation in the putamen. There were several other clusters of greater activation associated with better performance (higher accuracy) including angular gyrus, anterior cingulate, cuneus, insula, precentral gyrus, red nucleus, and supramarginal gyrus. Poorer performance (lower accuracy) was associated with greater activation in small fronto-striatal clusters (inferior frontal gyrus, middle frontal gyrus, precentral gyrus, putamen) as well as parahippocampus.

## DISCUSSION

We examined brain–behavior correlations in 9- to 11-year-old children engaged in a selective attention task requiring visual search of a conjunction of features and a response inhibition task requiring inhibition of a pre-potent response in no-go blocks. In general, we found that higher accuracy for the go no-go task was associated with greater activation in the response inhibition network, whereas lower accuracy on the visual search task was associated with greater activation in the spatial selective attention network. Higher accuracy in the no-go task of this study was associated with more activation in fronto-striatal regions that have been proposed to be epicenters in a response inhibition network [Casey et al., 2001]. Specifically, higher accuracy was associated with greater activation in prefrontal cortex (inferior frontal gyrus), supplementary motor cortex (medial frontal gyrus), and basal ganglia (putamen and caudate). All of these regions, except for the inferior frontal gyrus, were associated with both fewer false alarms and fewer misses. These areas showing a brain–behavior correlation are similar to regions that were activated in a previous developmental fMRI study of the no-go task [Booth et al., 2003]. This study showed activation for the children as a group in medial regions of the superior frontal gyrus (adjacent to the medial frontal gyrus) and in bilateral caudate and putamen. In keeping with previous developmental studies examining brain–behavior correlations during go no-go tasks in children [Bunge et al., 2002; Casey et al., 1997; Durston et al., 2002], our results found that higher accuracy among children was associated with more activation in fronto-striatal regions. The correlation of higher accuracy with basal ganglia activation may reflect the effective recruitment of this region for motor inhibition [Casey et al., 2001], whereas the correlation of higher accuracy with supplementary motor activation could additionally reflect the role of this region in motor planning, initiation, and internally guided action [Deiber et al., 1999; Jenkins et al., 1994; Mushiake et al., 1991].



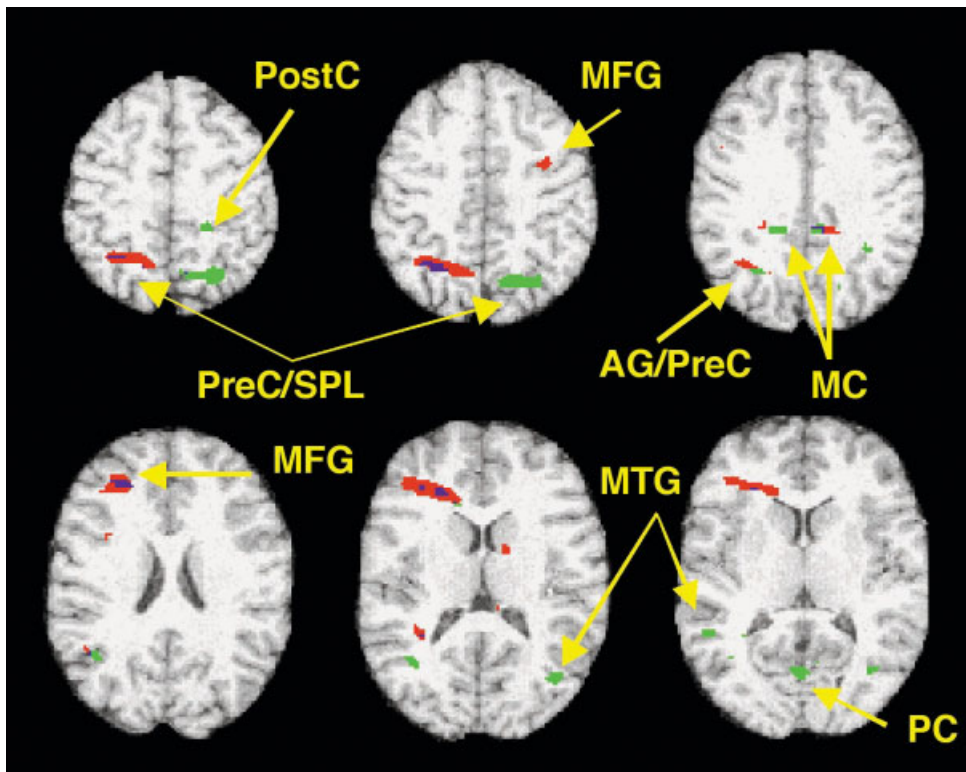
**TABLE II. Association of behavioral performance with activation for the selective attention task**

Location Area	BA <sup>1</sup>	Significance		Coordinate <sup>4</sup>		
		z-test <sup>2</sup>	Voxels <sup>3</sup>	x	y	z
Neg FA <sup>a</sup>						
Precuneus	7	5.31	68	-15	-42	45
	7	5.40	136	-12	-72	36
Cuneus	18	5.14	59	15	-84	15
Middle occipital gyrus	19	5.97	82	-36	-81	9
Neg MI						
Precuneus	7	4.25	75	18	-48	42
	7	5.28	52	-30	-45	30
Neg RT						
Middle temporal gyrus	37	4.06	63	45	-69	6
Pos FA <sup>b</sup>						
Precuneus/superior parietal lobule <sup>c</sup>	7	4.62	42	12	-51	60
	7	6.26	276	-24	-54	45
Middle frontal gyrus	6	4.51	30	36	3	45
Middle cingulate	31	4.34	45	21	-39	30
Middle frontal gyrus	46/10	6.21	306	-33	39	15
Caudate tail	<sup>d</sup>	5.36	84	-33	-45	12
Pos MI						
Superior parietal lobule/precuneus <sup>c</sup>	7	4.67	165	24	-63	48
Postcentral gyrus	3	4.41	45	24	-33	48
Middle cingulate	31	5.21	46	-18	-36	30
Angular gyrus/precuneus	39	6.15	203	-39	-54	27
Middle frontal gyrus	46/10	4.51	107	-15	36	18
Middle temporal gyrus	37	4.63	37	45	-69	15
	21	4.44	36	-51	-45	6
Posterior cingulate	30	4.80	70	-3	-69	3
Cerebellum	<sup>d</sup>	4.75	66	-12	-66	-36
Pos RT						
Postcentral gyrus/paracentral lobule	3/5	4.56	69	-42	-24	60
Paracentral lobule/middle cingulate	5/31	3.92	59	-6	-36	51
Middle frontal gyrus	8/6	4.39	64	48	9	42

<sup>1</sup> Brodmann's area of activation.<sup>2</sup>  $P < 0.001$  uncorrected at the voxel level.<sup>3</sup> Number of voxels in cluster; only clusters 30 or greater are presented.<sup>4</sup> x, left hemisphere, +x, right hemisphere; -y behind anterior commissure, +y in front of anterior commissure; -z below AC-PC plane, +z above AC-PC plane. Regions are sorted by z coordinate.<sup>a</sup> Negative correlations (Neg) indicate that lower errors (false alarms [FA] or misses [MI]) or reaction times (RT) are associated with greater activation.<sup>b</sup> Positive correlations (Pos) indicate that higher errors or reaction times are associated with greater activation.<sup>c</sup> These peak coordinates are plotted as a function of errors in Figure 3.<sup>d</sup> No BA for this region.

For the visual search task, we found that lower accuracy was associated with greater activation in bilateral superior parietal lobule (both for false alarms and misses) and right lateral premotor cortex (only for false alarms). These are similar to regions (BAs 7 and 6, respectively) that were activated in a previous study that examined group activation in children during a visual search task [Booth et al., 2003]. These essential components of the selective attention network seem to be involved in the representation of extrapersonal space and in the orientation of attention [Mesulam, 1990]. Lower accuracy children in our study may have found the visual search task more difficult and thus needed to recruit additional brain resources in order to perform the

task [Carpenter et al., 1999]. The finding of greater activation for children with lower accuracy on the selective attention task was not predicted from previous studies. Although previous developmental studies have not directly examined brain-behavior correlations for spatial selective attention tasks, some have examined correlations for spatial working memory tasks that engage many of the same neural components [LaBar et al., 1999]. These previous studies found weak or nonexistent correlations between activation and performance in the scanner [Kwon et al., 2002; Nelson et al., 2000]. The reason why these previous studies failed to find brain-behavior correlations such as ours is unclear. Perhaps the broader age range in these previous studies obscured the



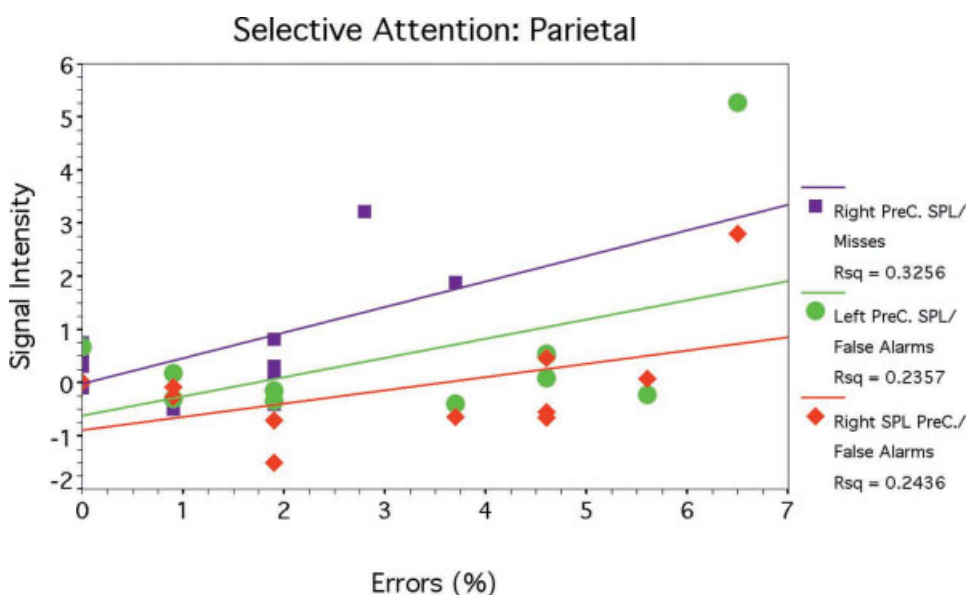
**Figure 1.**

Axial slices showing poorer behavioral performance associated with greater activation for the selective attention task. Red indicates false alarms, green indicates misses, and purple indicates overlap between false alarms and misses. AG: angular gyrus; MC: middle cingulate; MFG: middle frontal gyrus; MTG: middle temporal gyrus; PostC: posterior central gyrus; PC: posterior cingulate; PreC: precuneus; SPL: superior parietal lobule.

relation between behavior and attentional brain processes. We also found that higher accuracy during the visual search task was positively correlated with small clusters of activation in visual processing regions (including bilateral precuneus, right cuneus, and left middle occipital gyrus), but not in the superior parietal lobule. Perhaps better performers were able to rely on a visual processing strategy to perform the task with minimal reliance on attentional resources.

Consistent with this interpretation, learning studies have shown decreased reliance on superior parietal regions with increasing skill in mirror reading [Poldrack et al., 1998] and motor sequence acquisition [Muller et al., 2002].

The reason why higher accuracy was associated with increased activation in the go no-go task but decreased activation in the visual search task may be related to the differential maturational trajectories of the networks involved.



**Figure 2.**

Scatterplots showing poorer performance (false alarms or misses) associated with greater activation for the selective attention task. PreC: precuneus; SPL: superior parietal lobule.  $R^2$  for the regression lines are presented in the legend.

**TABLE III. Association of behavioral performance with activation for the response inhibition task**

Location		Significance		Coordinate <sup>4</sup>		
Area	BA <sup>1</sup>	z-test <sup>2</sup>	Voxels <sup>3</sup>	x	y	z
Neg FA <sup>a</sup>						
Medial frontal gyrus <sup>b</sup>	6	5.35	47	18	0	60
	6	5.09	146	−6	−18	57
Supramarginal gyrus	40	6.33	170	45	−36	27
Inferior frontal gyrus	46	5.01	34	−39	33	12
Anterior cingulate	32	4.66	53	6	39	12
Cuneus	18	4.05	37	0	−75	9
Insula/putamen	13/ <sup>c</sup>	5.4	430	−42	−3	6
Insula	13	4.21	43	48	3	−3
Putamen/caudate <sup>b</sup>	<sup>c</sup>	9.19	124	24	18	−6
Putamen <sup>a</sup>	<sup>c</sup>	4.62	45	−21	15	−6
Red nucleus	<sup>c</sup>	5.36	43	6	−27	−12
Neg MI						
Precentral/middle frontal gyrus <sup>b</sup>	6	5.11	231	−12	−36	66
Precentral gyrus <sup>b</sup>	4	4.15	34	27	−36	57
Supramarginal gyrus	40	5.53	131	45	−39	27
Angular gyrus	39	4.75	63	−51	−54	24
Putamen/caudate	<sup>c</sup>	7	33	24	18	−6
Neg RT						
Supramarginal gyrus	40	5.33	103	48	−33	30
	40	5.47	106	−60	−24	24
Superior Temporal gyrus	22	4.47	95	−51	−6	6
	22	4.95	87	57	3	0
Putamen	<sup>c</sup>	6.78	40	24	18	−6
Pos FA <sup>d</sup>	<sup>c</sup>	<sup>e</sup>	<sup>e</sup>	<sup>e</sup>	<sup>e</sup>	<sup>e</sup>
Pos MI						
Precentral/middle frontal gyrus	6	4.28	48	48	−9	39
Inferior/middle frontal gyrus	47/11	5.67	91	−21	27	−15
Inferior frontal gyrus	47	4.96	39	36	18	−18
Parahippocampus/putamen	36/ <sup>c</sup>	5.2	163	−24	−15	−21
Pos RT						
Paracentral lobule	5	5.14	34	−3	−36	57

<sup>1</sup> Brodmann's area of activation.

<sup>2</sup>  $P < 0.001$  uncorrected at the voxel level.

<sup>3</sup> Number of voxels in cluster; only clusters 30 or greater are presented.

<sup>4</sup> x, left hemisphere, +x, right hemisphere; −y behind anterior commissure, +y in front of anterior commissure; −z below AC-PC plane, +z above AC-PC plane. Regions are sorted by z coordinate.

<sup>a</sup> Negative correlations (Neg) indicate that lower errors (false alarms [FA] or misses [MI]) or reaction times (RT) are associated with greater activation.

<sup>b</sup> These peak coordinates are plotted as a function of errors in Figures 4 and 5.

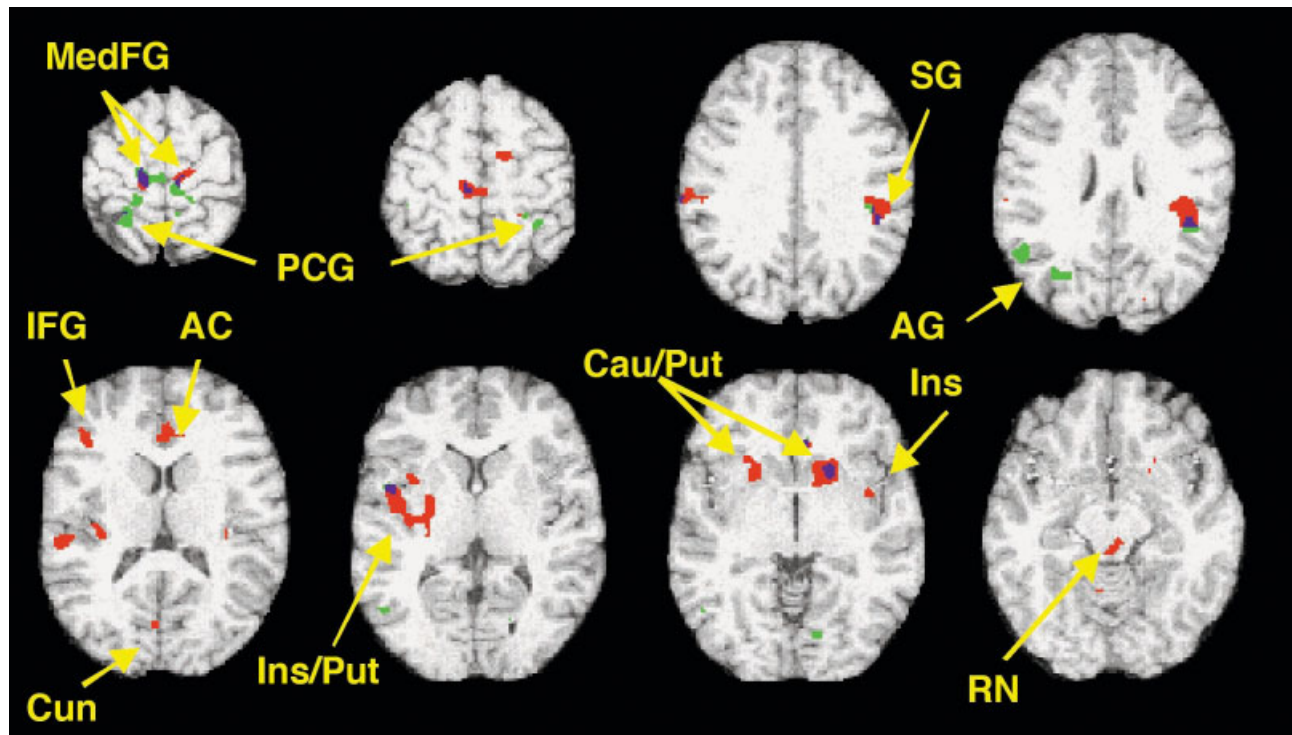
<sup>c</sup> No BA for this region.

<sup>d</sup> Positive correlations (Pos) indicate that higher errors or reaction times are associated with greater activation.

<sup>e</sup> No significant cluster for this correlation.

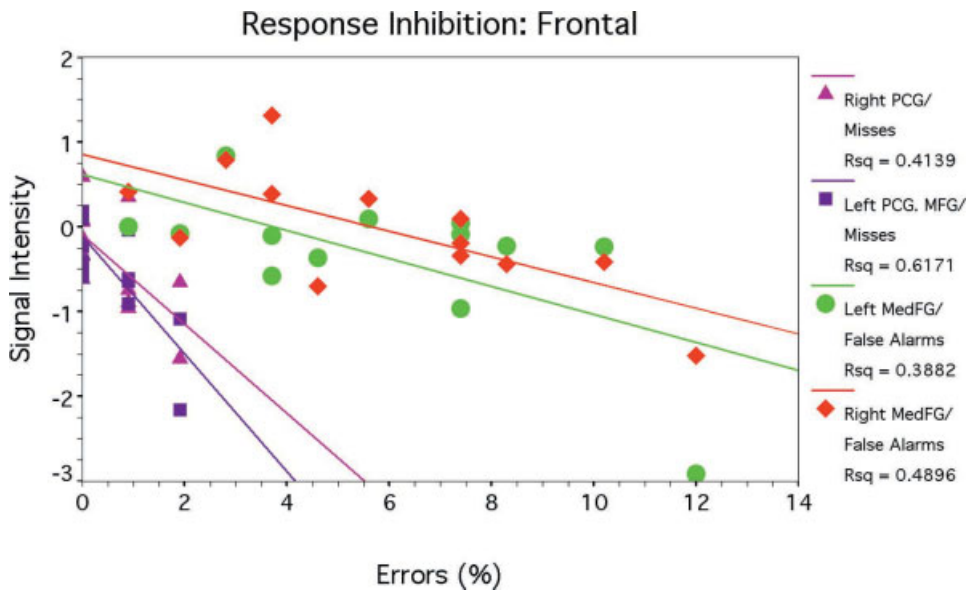
Several lines of research suggest that the maturation of fronto-striatal networks involved in response inhibition is more prolonged than the maturation of other cortical systems [Chugani et al., 1987; Giedd et al., 1999; Huttenlocher and Dabholkar, 1997; Sowell et al., 1999; Thompson et al., 2000]. In addition, Booth et al. [2003] found larger developmental differences in brain activation on a no-go task than on a visual search task. They suggested that this reflects the relative immaturity of the response inhibition network in 9- to 11-year-old children as compared to the selective attention network. Tasks that are mediated by relatively mature

brain networks in children may show negative correlations with accuracy because better performers are more automatic and efficient at utilizing existing neurocognitive resources. By contrast, tasks that rely on relatively immature brain networks may show positive correlations with accuracy because a more extensive utilization of the relevant neurocognitive resources becomes required to perform the task well. In conclusion, this study showed that the direction of brain-behavior correlations in children depends on the nature of the neurocognitive network. However, the range of error rates in our sample of children was rather low, so future



**Figure 3.**

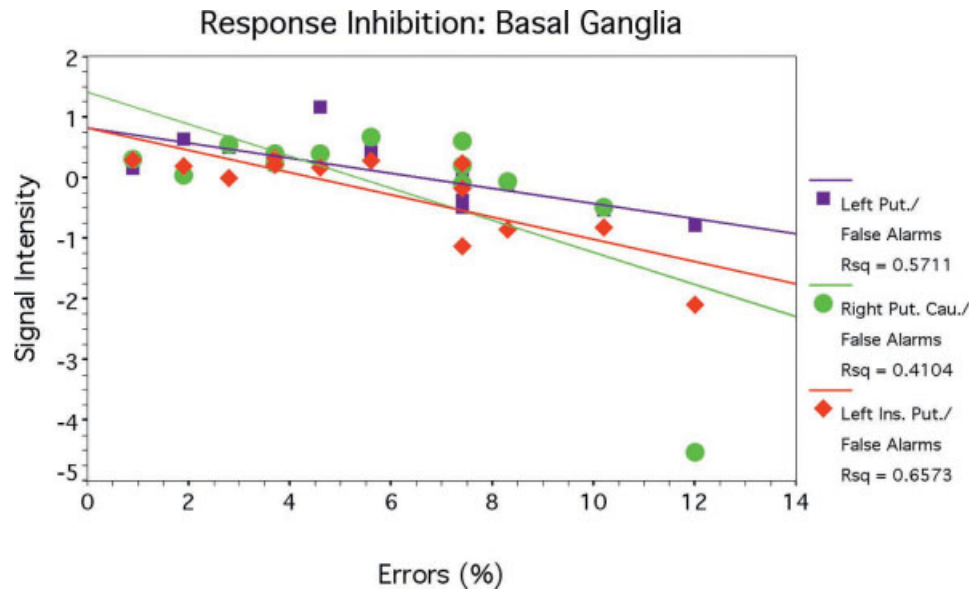
axial slices showing better behavioral performance associated with greater activation for the response inhibition task. Red indicates false alarms, green indicates misses, and purple indicates overlap between false alarms and misses. AG: angular gyrus; AC: anterior cingulate; Cau: caudate; Cun: cuneus; IFG: inferior frontal gyrus; Ins: insula; MedFG: medial frontal gyrus; PCG: precentral gyrus; Put: putamen; RN: red nucleus; SG: supramarginal gyrus.



**Figure 4.**

Scatterplots showing better performance (false alarms or misses) associated with greater activation in frontal regions for the response inhibition task. MedFG: medial frontal gyrus; MFG: middle frontal gyrus; PCG: precentral gyrus.  $R^2$  for the regression lines are presented in the legend.





**Figure 5.**

Scatterplots showing better performance (false alarms) associated with greater activation in basal ganglia for the response inhibition task. Cau: caudate; Put: putamen.  $R^2$  for the regression lines are presented in the legend.

research should address whether there is a linear relationship between performance and activation with tasks that produce higher error rates.

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